OSA

Approved For[redacted]ease 2002/10/16 : CIA-RDP67B0051[redacted]00100140014-1

OSA - 1297-62

13 September 1962
#136-022

Dear Jack,

Inclosed for your information is a copy of a thermal test report that we discussed on 30 August.

The results indicate that good performance can be achieved with the expected internal environment. The tests did not, of course, simulate the external environment.

The preliminary test plan is also inclosed. The assumptions on which it is based may or may not be valid, but a meeting at Ed M.'s shop is tentatively planned for the week of September 14 or September 21. After the meeting a more detailed plan can be prepared and a tentative schedule arranged.

WRE/map

Wayne
W.R.E

Enclosures (2)

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Copy No. 12
Sheets 3

August 7, 1962

ENCL #1
OSA = 1295-62

To: [redacted]

From: [redacted]

Subject: Tentative "P" Test Program

Reference: Memo For Record, BLE-1013, dated May 13, 1962

A tentative "P" Test Program has been established contingent upon vehicle test variables such as flight profile and V/H range. The program below assumes a complete system operable and is followed by variations should they be necessary.

Phase A - Ground Operation

1. System operation in vehicle using vehicle ground power equipment.

2. Shake Test on I-S mounted system in vehicle. All camera components affecting operation must be measured for undesirable vibration modes.

3. System operation in vehicle using vehicle engine power if feasible.

Phase B - General System Parameters (4 Flights)

1. Flights to establish focus, verify exposure, and define operational capability with or without V/H sensor.

   a. Equipment focus and exposure must be sufficiently accurately determined to evaluate thermal program to follow.

   b. During this test, thermal equipment is to operate at best predicted condition.

   c. Equipment to be operated partially from programmed V/H and partially from V/H sensor.

   d. Test I-S System if thermal situation allows. If not, this test will be accomplished under Phase D.

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Phase C - Thermal (4 Flights)

1. Operate with blanket heaters for as long a flight profile as possible, up to maximum normal-cruise flight duration.

2. Repeat without blanket heaters.

3. Evaluate performance versus time under simulated or real flight profile conditions.

4. Use performance versus time data to fly complete programmed focus and flight profile test.

Phase D - System (3 Flights)

1. Total system test.

2. Total system test.

3. Total system test.

Variations:

Condition I: In event the vehicle operates at the predicted lower speed capability, and at full altitude, the following changes are anticipated:

a. The first thermal test (with blanket heaters) will not be necessary.

b. The test flight program would attempt partially to simulate the final article condition to be met later. This simulation would appear in one of the latter tests.

c. The V/H Sensing Device will NOT be operational. Programmed V/H will be used throughout. A gear drive change would be used instead of new cams if an error analysis now being made on the cams will allow.

Condition II: In event the vehicle can be operated at the predicted lower speed capability, and at K20 to K25 altitude, the following changes are anticipated:

a. The first thermal test (with blanket heaters) will not be necessary.

b. Inasmuch as the V/H would be approximately 0.029, the V/H Sensor or a Programmed V/H could be used with the present cams and gears. Further investigation may deem it desirable to make a gear change so as to operate nearer the 400 cps nominal drive frequency.

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Additional Comments:

As soon as the acutal test flight profiles are known, a program of focus position versus time will be tentatively determined from the in-house thermal test data. Instrumentation will be planned so as to monitor this program in flight both thermally and for focus position.

A time schedule to accompany this field test series will be prepared as soon as actual vehicle operation parameters are known.

DJS:rkg [redacted]

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Copy No. 19
Sheets 25

July 31, 1962
Serial: JJM-318
ENCL #2

OSA - 1297-62

MEMO FOR RECORD

From: [redacted]

Enclosures: 1. Table I - Tabulation of Several Measured and Computed Temperatures

2. Thermal Photographic Tests - #13, #14, #15, and #16 and Thermal Tests -------------- #17 and #18

3. Schematic Diagram of Simulated "Oven-Bay" "Lens Cooling" Thermal Test Set-Up

Subject: Simulated Oven-Bay Thermal Test Results

I. Introduction:

This memo documents the results of a series of thermal tests conducted "in-house" during the period from June 5, 1962, to July 26, 1962. The tests were conducted to provide a preliminary evaluation of the basic features of our configuration thermal design. These features will be incorporated, during future field tests, when the system is subjected to a severe thermal environment.

As a brief review, the major thermal design features in question include the insulated wall or so-called Oven-Bay enclosure surrounding the main optical window and panning mirrors, and a cooling jacket which is furnished with controlled temperature cooling air around each lens unit. Optical communication between the panning mirrors, located inside the Oven-Bay, and the lens units, located outside the Oven-Bay, is through two double-glass thermal vacuum window units mounted in the oven-wall immediately in front of each lens unit. To carry away heat flowing toward the lens elements from these windows, the lens air cooling supply is first routed into a narrow cavity formed between the vacuum window units and the front element of the lens assembly.

The overall ambient environment will be air at an absolute pressure of 1.5 psi. The temperature at the lens units will remain constant at about 84°F; however, within the Oven-Bay it is expected that the temperature will range from -20°F to 490°F. Accordingly, the main optical window, the thermal vacuum window units, and the panning mirror units will all be subjected to severe thermal transients, potentially high heat fluxes and large thermal gradients during the entire period of recorder operation. To minimize thermal gradients and heat flows, the panning mirrors will be fabricated of either aluminum or beryllium and the inside surface of the oven cavity will be finished to a low emissivity.

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I. Introduction: (Continued)

To date, we have had no actual flight experience with high resolution optical recording systems operating within such an adverse thermal environment; yet, an analysis indicates that the thermal design briefly described should provide adequate protection and enable the system to produce good quality results. To gain some experimental support for the adequacy of this design the "in-house" thermal tests were designed to closely siumlate the conditions expected during operation with the actual hardware. In reality, it was not possible to include those effects which will be produced by the main optical window and external boundry layer, but otherwise the tests can be considered close approximations to the actual situation.

II. Conclusion:

Excluding any unforseen disturbances that might be caused either by the external boundry layer or by thermal gradients in the main optical window, which factors were not made a part of this testing program, it may be concluded that our current "Oven-Bay - Lens Cooling" design concept will be successful in providing an optically compatible system and should enable our configuration to perform and meet the system resolution design goals within the anticipated surrounding thermal environment.

This conclusion is supported by the test results in Section IV of this report.

III. Summary of Recommendations and General Comments:

Functionally the "Oven-Bay - Lens Cooling" thermal design concept is satisfactory, but a large amount of work still remains in order to put the actual hardware into good working condition and to mechanically fit it to the P-Model configuration. The assembly work will be both time consuming and painstaking and extreme care will be necessary to fulfill all design requirements.

The Oven-Bay walls and lower convection barrier must be meticulously fitted to allow freedom of movement both for the sector arms and for configuration attitude corrections. Further, the walls must achieve their purpose of providing a maximum of thermal insulation and the least possible number of exposed holes and cracks. A considerable amount of care will be required to locate and support both the heating blanket and the aluminum hardshell inside the oven cavity in order to avoid interference with the panning mirrors; and proper attention must be given to providing the low emissivity requirement (0.1 or less) on the interior surface of the cavity hardshell.

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III. Summary of Recommendations and General Comments: (Continued)

To avoid the accumulation of volatiles, which can condense in thin films on the panning mirrors and vacuum windows, all parts used within the Oven-Bay must be thoroughly cleaned and pre-baked at a minimum temperature of 500°F. In connection with this problem, possible oil contamination of Oven-Bay parts, during operation, from the vehcile cooling air may prove to be troublesome, and may necessitate the use of an Oven-Bay plastic hood protector.

A critical review appears to be in order for all structural fasteners used within the hot Oven-Bay in order to be certain that they will not loosen-up during operation. In this review careful attention should be given to the flexure pivots supports used for mounting the panning mirrors.

The vacuum window units are satisfactory as currently designed and fabricated; however, using the gold "emissivity-control" coating as a window heater produced undesireable image results and therefore, it will not be used for this purpose during future operation. Accordingly, all electrical controls associated with these heaters can be eliminated.

The controlled temperature air cooling system for each lens unit works exceptionally well. It is self-balanced for air distribution, and following assembly will require only one pre-flight test to adjust the recommended temperature control setpoint somewhere between 83°F and 85°F. To avoid air "flutter" all forms of thin, tubular, plastic film materials must be avoided in the air supply duct work. In addition, all air handling components such as ductwork, lens cooling air distribution plenums around the lens units, air preheaters, gyro cooler, and the air filter must be securely mounted.

A potentially serious problem was discovered in connection with the possibility of temperature damage to the surface of the mirrors at temperatures over 400°F. A thorough investigation should be made to determine the reliability of the current coatings at high temperature and possible methods by which the durability of these coatings can be improved.

Complete success of our system requires, not only an individual acceptable operational performance, but that it be compatible with both the vehicle and stable platform interfaces. Mating of thermal hardware with the vehicle and stable platform, should proceed at the earliest possible date. In particular, an early evaluation is needed of the disturbing torques and resistances which the lens air cooling system and Oven-Bay convection barriers will add to the stabilization system.

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IV. Results and Discussion

A. Environment

An atmosphere of air at an ambient pressure level of 1.5 psia (3.06" Hg abs) is sufficient to avoid atmospheric boiling and optical "shimmer-pattern" degradations even with Oven-Bay wall-to-wall temperature differences as great as 250°F.

At no time during the test program was evidence noted of "shimmer-patterns" created by the heated air atmosphere within the test cavity. Repeated examination for this effect was made by visual observation, using a 100X microscope, under widely varrying temperature gradients.

It might be added, that on one occassion an attempt was made to determine the level of pressure which will cause atmospheric boiling. In this particular test the cavity walls were not being heated, but were maintained at the final steady state temperature levels for the case of a non-heated Oven-Bay wall. An absolute critical pressure value was never obtained, but it was observed that a total pressure in the order of 2.5 psia appeared questionable. As such, the intended operating level of 1.5 psia allows an ample safety factor.

B. Air Cooling of Lens and "Lens-Vacuum Window" Cavity

At a cooling-air mass flow rate of 3 lb./min. which is first injected into the cavity located between the vacuum window and the lens and next removed by passage from front to rear along and through the lens assembly, no evidence of optical photographic degradation of any type was detected. Numerous trials to induce vibrations in the lens and other critical optical components by cycling the air "on" and "off", and by varying the mass flow to as high as 6 lb./min. all failed to show any degrading effects on image quality. Repeated attempts to trace occasional vibrations back to this air supply system were unsuccessful. Intensive study of the image with a 100X microscope, detected no atmospheric boiling, or image "shimmer effects", induced by this cooling air system over a range of vacuum window surface temperatures exceeding 400°F inside the oven test cavity. In fact, as reported under miscellaneous findings, the cooling effect of this air system actually avoided atmospheric boiling and "shimmer" outside of the test cavity, which was occurring during initial tests, when the outside surface of the inlet vacuum window became warm. At a critical temperature level which was reached at about the midway-point of each test, boiling would begin. The lens cooling air system, when applied to this window, corrected the problem.

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B. Air Cooling of Lens and "Lens-Vacuum Window" Cavity (Cont'd.)

The main purpose of this cooling air together with the attendant air preheaters and temperature control system is to maintain an isothermal lens throughout the entire operational mission. To accomplish this, a pre-determined maximum lens temperature level is selected, arrived at on the basis of expected maximum heat gains to the lens from the Oven-Bay vacuum window. Prior to heat generation within the Oven-Bay, the air preheaters maintain this setpoint temperature, but as heat is evolved from the Oven-Bay, a proportional temperature controller throttles the preheaters off in order to maintain the lens setpoint temperature. Thorough and numerous tests of this control system showed that it works as designed. Variations in lens temperature across the first lens element were less than 2°F, even when the air environment on the underside of the cooling jacket was heated to about 145°F, and the total variation in temperature from front to rear of the lens never exceeded 3°F. This control was maintained under conditions of air inlet temperatures varying up to 5°F, and with Oven-Bay heat loads ranging from zero to steady state maximum. In addition to recording temperatures, further evidence of control was obtained by observing periodic increases and decreases in electrical power supply to the preheaters.

C. Photographic Resolution

As listed in Step D. below, the photographic resolution, recorded on SO-243 film using a USAF 1951 resolution chart (reproduced 4:1 lines/mm) was limited by a great number of factors. Nevertheless, resolutions made with both 1/60 sec. tungsten filament expsoures and 1/1000 sec. strobe light (through a 0.4 N.D. filter) exposures exceeded 100 lines/mm (both directions) throughout the entire two hours heating period of all tests conducted without heated cavity walls, but dropped to about 60 - 70 lines/mm from about the midpoint to the end of each test where the cavity walls were heated.

The decrease in resolution, on those tests employing the use of heated cavity walls, apparently resulted from an introduction of larger thermal gradients in the mirror, and greater unsymetry in the center to edge temperature isotherms on the two vacuum window units. These larger temperature gradients were a direct result of an increase in the rate of heating of these optical components, as influenced by the warmer cavity walls.

Resolution read with a 100X microscope was usually in the order of 180-228 lines/mm regardless of the various test conditions and parameters. On occasion, during those tests where the cavity walls were heated, microscope readings as low as 128 lines/mm were obtained, but there was always the question as to whether these low readings might not actually have been caused by building vibrations. Microscope examination never revealed clear, unmistakeable evidence of image astigmatism caused by thermal effects, although on occasion, usually in the case of a heated cavity wall test, some astigmatic signs were indicated.

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C. <u>Photographic Resolution</u> (Cont'd.)

All photographs and microscope readings were made with a red filter in the system located in the optical path just ahead of the vacuum window unit which admitted the image from the collimator to the test chamber.

Because of vibration and lack of source intensity, the 1 ms strobe exposures were much more reliable and more repeatable from test to test than were the 1/60 sec. tungsten filament exposures. Enough crossover data was obtained, under fairly ideal conditions of vibration and exposure light intensity, however, to affirm the fact that the 1/60 sec. exposures under proper conditions resulted in giving nearly equal resolution readings. Thus, it is believed no favorable advantage has been taken in reporting resolution readings made with the 1 ms strobe light source.

In all tests, inspection of resolution as a function of mirror thermal hisotry definetly showed a loss in resolution as the recorded rear surface mirror gradients began to peak. The gradient usually peaked at about 40 minutes, following which this peak decreased only slightly throughout the balance of the two hour test. With regard to this fact, it should be mentioned at this point, that these tests were all conducted with considerable disadvantage in terms of mirror thermal gradients. All tests involved starting with a cold 75°F mirror and raising the surrounding wall temperatures rapidly to 500°F in accordance with the anticipated rate of heating during the second phase of the actual mission. Thus, this test condition imposed a severe thermal gradient between heat source and the mirror with subsequent high flux heating during the entire photographic period of the test. Under actual operational conditions the mirror will be preheated during the first phase of the mission to about the same temperature level to which the mirror arrived near the end of these tests. In other words, the mirror will be preheated prior to actual system operation and the thermal gradient between both the mirror and the oven walls and between the mirror and the optical window, will be much smaller (less than one half over the entire mission) than it was in these tests. This in turn will produce less heat flow to the mirror and result in much smaller mirror thermal gradients. Since resolution is definitely a strong inverse function of mirror distortion, the optical limitations from this thermal gradient source will be considerably smaller under actual operating conditions. It might further be stated that mirror thermal gradient improvements will be achieved, during actual operation, as a result of the panning action of the mirror.

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D. Photographic Resolution Limited By --

1. Building and equipment vibration and camera shutter vibration.

2. Poor surface quality (greater (poorer) than 0.1 wave flatness) of mirror, particularily in pheripheral areas which were included in the optical path of these tests. Also, the surface was badly scratched, pitted, and discolored. Further, during each test, the mirror accumulated to a greater or less extent a thin film of fog by condensing volatiles released from other materials contained within the heated enclosure.

3. Thermal gradients within mirror and somewhat non-linear thermal gradients within the two vacuum window units.

4. Lack of achieving best image focus because of a continuous change in system focus resulting from the vacuum window thermal gradients.

5. Lack of achieving best image exposure on the SC-243 film record of the photographic results. This was caused by foreign material deposits on the mirror surface, optical path vignetting, and the use of two heat reflecting coated (light restricted) vacuum window units in series.

6. Accumulation of dirt, lint, oil films, etc., on the vacuum window surfaces and various lens elements. An attempt was made to keep the windows clean, but nothing could be done to clean the interior of the lens.

7. Mirror flexure pivot supports were somewhat loose and permitted mirror vibration.

Note: Numbers 1, 2, 4, 5, 6, and 7 should not be present in actual system operation.

E. Mirror Thermal Gradients

The exact difference between thermal effects on the mirror for the case of heated versus non-heated cavity walls is hard to define from these tests. In the case of measurements made with thermocouples that were buried within the mirror, 1/4" from the front face on 4" diameter and 8" diameter isotherms, there was no apparent difference in any of the isotherm temperature readings for the case of non-heated cavity walls, but about a 1°F difference in several of the readings when the cavity walls were heated. For the case of surface temperature measurements, taken on the back side of the mirror, the effect was more noticeable as shown by the fact that a maximum gradient (read from center of mirror to chamfered top corner) of 14°F was measured for the case of heated oven walls, and only 8°F (43% reduction) for the unheated case.

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E. Mirror Thermal Gradients (Cont'd.)

Regardless of the gradients obtained in this test series, the data is probably not too meaningful in terms of predicting what can be expected during actual operation since the rate of mirror heating and subsequent thermal gradients will undoubtably be much less in actual operation due to the operational mirror preheating cycle explained under Step C. above. Further, the actual Oven-Bay to mirror geometry is considerably different in the case of configuration hardware which will also influence the operational temperature gradient.

F. Vacuum Window Thermal Gradients and Heating Symetry

A general summary of the vacuum window gradients and possible degree of heating symetry follows:

All data is based on tests using low emissivity cavity walls.

1. The maximum temperature gradient from center to edge of the window was --

   a. -28°F inside the oven and -10°F outside the oven (in lens cooling cavity) for the case of heated oven walls and was

   b. -23°F inside the oven and -4°F outside the oven for the case of a non-heated cavity.

2. The largest difference between four edge temperature readings taken at 90° intervals around 360° of the hot side of the vacuum window was 6°F in the case of a heated oven cavity, and 4°F in the case of non-heated walls.

3. The maximum amount of apparent unsymetry in center to edge gradient on the cool side of the window (inside lens cooling cavity) as determined by the greatest variation in edge temperature from an average edge temperature was about 6°F for both the case of heated oven walls and for the case of non-heated walls.

From this data, it can be seen that in these tests a slight improvement was obtained in terms of smaller thermal gradients and perhaps greater heating symetry in the case of non-heated oven walls; but, since the actual hardware geometry will be different, it cannot be definitely concluded that non-heated Oven-Bay walls are an advantage from this standpoint.

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G. Heated Cavity Wall Comments:

On the basis of the film resolution data and the miscellaneous window and mirror gradients obtained on these tests, and discussed in previous sections, one might conclude that non-heated oven walls are definitely superior to a heated cavity and that accordingly, we should not employ a heating blanket in the Oven-Bay. In the actual case of operating with configuration hardware, the situation will be different. As previously explained, the mirror will be preheated and will be moving, and thus the temperature gradients will be much smaller even with heated cavity walls.

Of even greater significance however, is the fact that these tests included no data on the effects which thermal gradients in the main optical window will have on the system or on the effects of fairly large heat leaks in the Oven-Bay walls. The actual operational performance of our system will be influenced by both of these factors which originally formed part of the justification for oven-wall heaters in our design.

In terms of possible benefits to the optical window, heating the oven walls, will reduce heat flow from the main optical window which in turn will minimize window thermal gradients (See Step P.8. Below). Relative to oven-wall heat leaks, the actual configuration wall hardware is very cut-up and is not a uniform wall thickness; also, it will be further complicated in respect to heat leaks due to the lower convection barriers. Oven-wall heaters should definitely be advantageous in countering the effects of heat leaks from this construction.

Tentatively, it will be planned to be able to operate either with or without an Oven-Bay heating blanket in the P-Model configruation.

H. Oven Cavity Wall Finish

Clear, evidence was obtained that a low emissivity (this is, such as can be obtained by a shiny polished aluminum surface) oven cavity produced lower thermal gradients, particularily in the mirror, than did a high emissivity cavity surface, and accordingly, produced some improvements in the photographic resolution of the tests. This effect was much more pronounced, as would be expected, in the case of heated oven cavity walls, in which case about a 30% reduction in the mirror rear surface thermal gradient was achieved with the low emissivity cavity walls. No problems of light scatter or flare was evident during use of the polished aluminum walls.

It will be planned to use a low emissivity oven cavity surface in the configuration. It might be added that this feature also makes a sizeable reduction in total heat input to the system, which is a desireable characteristic. The desireability of a low emissivity cavity surface was also formerly shown by computations.

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I. Vacuum Window Heaters

One short test was conducted using the heater coating on one of the thermal vacuum window units in an effort to reduce thermal gradients between the inside glass surface and the heated cavity surround. The heater and control circuit worked perfectly, but the rapid thermal transient and miscellaneous thermal gradients imposed on the window caused complete loss of image resolution. This effect was most clearly observed by inspection with the microscope and it persisted for as long as 10 minutes following turning the window heater off.

It has been decided not to use these heaters on the configuration hardware in which case the vacuum window surface will operate as a floating thermal potential influenced only by the relatively mild and fairly uniform heat fluxes it receives from the oven cavity. This will result in a thermal gradient as high as 250°F between the window surface and the walls of the oven cavity, or about one half this amount between the window surface and the Oven-Bay ambient; however, there is no evidence that this large temperature gradient will result in degrading the image by causing atmospheric turbulence in the optical path.

J. Optical Window Emissivity

Even though it is currently planned that operation will be necessary without a true low emissivity coating on the main optical window, a series of tests were conducted, as a matter of interest, using a low emissivity source (bottom of the test box) in conjunction with low emissivity cavity walls. Considerable improvements were noted over those tests where the source was of normal glass emissivity, namely:

1. The mirror rear surface thermal gradients were reduced about 40% in the case of non-heated cavity walls, but there was little or no change in the case of heated cavity walls.

2. The total power input was reduced perhaps about 20%.

3. The average mirror temperature was reduced about 50°F in the case of non-heated cavity walls, but little change in the case of heated cavity walls.

4. The center of the inside surface temperature of the lens vacuum window unit was reduced about 90°F in the case of a non-heated oven cavity wall and about 30°F in the case of a heated cavity wall.

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J. Optical Window Emissivity (Cont'd.)

While this data shows it is definitely desireable to have a low emissivity on the surface of the main window, optical considerations require that this be accomplished by means of an extremely thin gold coating, and thermal test experience has repeatedly shown that these thin coatings do not serve to thermally provide a low emissivity source. The thickness requirements for thermal considerations are at least 1000X greater than can be tolerated optically.

K. Focus Shift

A focus shift of approximately 0.014" maximum, in the negative direction, resulted from the thermal gradients produced in the various optical system test components used in this test series. It is believed the major influencing factor was edge to center gradients in the two vacuum window units which in effect added optical power to these four pieces of glass. Since the eventual system will use only one vacuum window unit in series with the main optical window, and since it is hoped to avoid a gradient in the main window, by proper emissivity control around this unit and by employment of a heated interior oven-cavity, the operational focus shift due to thermal environment may be less than this 0.014". In any case, a value of 0.014" does not appear unreasonable.

L. Temperature Controllers and Sensors

The action of all temperature sensors and controllers for both the oven cavity heating blankets and the lens cooling air preheaters were entirely satisfactory. The control sensitivity was within the design specifications established for these systems.

M. Heating Blanket and Air Pre-heater Power

While the test system oven-cavity was not exactly like the Oven-Bay hardware intended for operation, it was close enough to verify that the computed value of 700 watts for the capacity of the Oven-Bay heating blanket will be satisfactory to control the oven walls at the same temperature as the optical window through the entire period of transient heating.

Based upon 78°F air supply to the lens cooling air pre-heaters a total pre-heater capacity of 100 watts for front and rear lens-duct air pre-heaters (60 watts front and 40 watts rear) will be satisfactory. The steady-state temperature control set point for the lens units should be somewhere between 83°F and 85°F, the exact value is not important.

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N. Vacuum Window Heat Gains

Maximum heat gains through the vacuum window units to the lens cooling air systems will be in the order of 150 BTU/hr. ± 100 BTU/hr. for each lens system, depending on the level of vacuum in the window units. Failure to achieve high vacuum in the window units will not result in serious heat flows, air turbulence between the pieces of glass, or other thermal-optical degradation. Maintaining a good vacuum is desirable from the standpoint of raising the temperature of the glass surface inside the oven cavity thereby reducing its thermal effects on the mirror.

Employment of a heat reflecting coating on these window surfaces is essentially non-effective from a thermal standpoint and accordingly if significant benefits in terms of increased exposure can be derived by not employing these coatings their use, at the vacuum window location, can be eliminated.

O. Surface Temperatures

Considering differences in geometry, weight, thickness of thermal insulation, etc., between the test cavity and those used for computations on the actual hardware, the experimental data temperature measured on various surfaces agreed well with those anticipated by computation. For a compilation on some strategic points, see Table I. Also attached to this report are temperature curves drawn for tests #13 through #18. These tests cover the cases of high and low emissivity oven cavities, both with and without heated oven walls, for the simulated case of a high emissivity main optical window. Also plotted on the curves, as a function of time and temperature, are film and microscope resolution values, focus change, lens temperature hisotry, and miscellaneous notes applicable to each individual test. The curves identified as "aim curves" are based on computations of expected performance with the actual hardware. These curves are typical of all others conducted in the experimental program.

P. Miscellaneous Findings

1. All materials planned for use in the Oven-Bay must be carefully selected for compatibility of operation in an environment of 500°F and 1.5 psia. All parts of the entire Oven-Bay assembly must be degreased or otherwise cleaned and pre-baked at 500°F - 600°F for several hours to thoroughly remove all materials which volatilize below 500°F. Otherwise, these volatiles will condense on the cool mirror surface as a result of the mirror thermal time lag during system operation, and will greatly effect the light intensity and exposure level. Also, this film of condensate produces a very diffuse type of light source which in itself degrades the image quality.

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P. Miscellaneous Findings (Cont'd.)

2. The high mirror temperatures can result in blistering of the aluminizing and silicon monoxide overcoats on the mirror surface. This effect became noticeable between 400°F and 450°F.

3. The wide ranges of cyclic temperature on the mirror can result in loosening the flexible pivot mounting bolts. This causes lack of mirror support with subsequent inducement of mirror vibration.

4. The outside surface temperature on the first piece of glass in the vacuum window unit, if not cooled by the lens cooling air system, was warm enough to cause severe atmospheric boiling, in the optical path outside the vacuum chamber, at 14.7 psia ambient pressure. This resulted in complete loss of image resolution. However, operation of the lens air cooling system wherein cooling air is injected into the cooling cavity located between the outside surface of the vacuum window unit and the first element of the lens, prior to its passage along the lens barrel, completely avoided this problem even at the high pressure level of 14.7 psia. This offers positive proof that this air cooling system will cause no image loss as a result of air motion particularly when the actual system will be operated at a pressure of only 2.0 psia.

5. The striped pattern (.345" wide stripes and .015" clear spaces) used to make a heater out of the heat reflecting coating used on one glass surface of each vacuum window unit caused no apparent optical image degradation.

6. The injection plenum design used to first introduce the lens air cooling air into the lens vacuum window cooling cavity (forward of the first lens element) will provide a uniform distribution of air around 360°F of the cooling cavity. This was checked by observing various cavity surface temperatures following the injection of a supply of heated air. The lens cooling air pre-heaters, located in this plenum, were used to heat the air which in turn offered further evidence that the heater design provides uniform heating of the lens jacket cooling air.

7. The use of thin plastic sheet materials such as .003" polyethylene tubing for the lens cooling air ducts can cause serious air "flutter" particularly if a slight bend is made in the direction of air flow. In no case should this type of ducting be used, as has been suggested to conserve weight.

8. These tests were all conducted with a uniform power input to the bottom heating blanket. This heater was used to simulate the heat input which will occur from the main optical window in the actual vehicle. In all tests a substantial gradient (50°F - 100°F) occurred between the center of the bottom and the edge, even with the constant power input surface density.

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P. Miscellaneous Findings

8. (Cont'd.)

This would indicate strong convective cooling effects which usually occurs in a cellular-type pattern inside enclosures of this type. This effect was less pronounced in those tests where the inside cavity walls were also heated, and thus lends support to the use of a heating blanket for reducing window gradients in the actual vehicle.

In the actual vehicle, the power input density will undoubtedly not be uniform but will most likely be higher at the edges. This, of course, is in the right direction since the additional inside cavity cooling effects at the edges will tend to correct this situation resulting in less window edge-to-center gradient than would otherwise exsit.

9. An interesting observation made during these tests which may prove to be practical significance in reducing center to edge gradients in the windows was made during Test #17. It was noted that one thermocouple used to measure edge temperatures of the vacuum window, inside the oven cavity, was reading as much as 10°F lower than all of the other edge thermocouples. The reason resulted from the accidental protrusion of a 1/8 x 1/8 mesh fine aluminum wire screen in front of the thermocouple. It would appear that purposeful employment of such wire mesh in front of the windows, with perhaps graduated mesh density from center to edge would greatly reduce the actual window thermal gradient. A loss of light would result, but the loss would probably be tolerable. It is doubtful that a serious defraction pattern would occur for locations ahead of the lens.

V. Experimental Set-Up and Test Apparatus

The attached schematic sketch shows the general arrangement of the test set-up. Following is a description of the major equipment components. Photographs of the apparatus were taken, but are not being made part of this report.

1. Image Source

U.S.A.F. 1951 resolution chart (reporduced 4:1 lines/mm) projected through the special 84" collimator test fixture system by means of either a 1 ms strobe light or a 500 watt tungsten filament bulb.

2. Vacuum Window Units

P-Model design Drawing Number P-700-D-001, two surfaces coated with special gold heat reflecting coating. One of these coatings, on each unit, was scribed to form coating stripes to be used as a heater for these windows.

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V. Experimental Set-Up and Test Apparatus (Cont'd.)

3. Mirror

2-3/4" overall height (1/2" minimum thickness) ribbed aluminum unit, Drawing Number P-400-D-104, provided with a fused porcelain surface followed with a series of silicon monoxide coatings (polished between coatings) then aluminized and finally overcoated with silicon monoxide.

Surface, prior to test series, exhibited visible crazing and was considered unusable for flight testing in P-Unit. Optical flatness was within 0.1 wavelength in center portion, but questionable in peripheral regions.

4. Mirror Support

Special Test Assembly, Drawing Number T-137, mounted to one of the side walls of the vacuum box enclosure.

5. Vacuum Enclosure, Cavity Wall Heaters and Controls

Special 2' x 2' x 2' x 1/8" thick wall aluminum box reinforced with 2" x 1/4" aluminum ribs on 4.8" centers, one wall removable per Drawings Numbers T1-P-700E-145, -146, and -147. Box insulated with 2-3/4" thickness of Owens Corning CM-215 insulation. All walls heated with special Chromolox, fiberglass coated resistance wire mesh heating blankets (See Step V.11. below for power). Temperature control provided with Minco Products #S8B sensors and Harrell Model #TC-100 relay type temperature controller. Inside cavity dimensions 1.5' x 1.5' x 1.5'. Inside cavity wall emissivity provided by special finishes on 0.020" aluminum plates located against face of heating blankets.

6. Lens

J26, f/4, 21" lens, air jacketed, F-Model design.

7. Camera

Kodak Signet 80, lens removed. Focus controlled with a special micrometer screw arrangement and dial gage indicator.

8. Lens Cooling Air Pre-heaters, Temperature Controller and Air Injection Manifold

P-Model air jacket design per Assembly Drawing Number P-700-E-035; 60 watt front jacket and 40 watt rear jacket heaters Drawings Numbers P-700-D-036 and P-700-B-079; Minco Products #S9B self adhering temperature sensors and Harrell Model #TC-202 proportional temperature controller.

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V. Experimental Set-Up and Test Apparatus (Cont'd.)

9. Microscope

B and L 100 power.

10. Thermometry

30 gage copper-constantan, fiberglass insulated thermocouples attached with special aluminum coated fiberglass high temperature adhesive tape (PD455). Readings recorded by a Minneapolis-Honeywell Type 153 Universal Electronic Multipoint Temperature Recorder (0°F to 500°F range).

11. Heating Blanket and Air Pre-heater Temperature and Electrical Controls

A special electrical control box was fabricated to include heating blanket, lens cooling air heater, and vacuum window heater temperature controllers, relays, "on-off" switches, reference resistors for lens air heater controllers, and miscellaneous interconnecting control wiring per Wiring Drawing Number T1-700-D-222. The blanket temperature sensing elements were purchased from Minco Products, and the temperature controllers were purchased from Harrell. These are the same units that will be used in the actual configuration. The cavity wall heating blanket electrical power consisted of a regulated 130 V, 1 PH, 60 cycle supply to the primary of a transformer, and 27 V secondary supply to the five cavity wall heating blankets during automatic operation. This provided about 700 watts total power to the five cavity wall blankets. The reference heating blanket, on the bottom of the box, was furnished with 130 V line power stepped down to the desired level for achieving the time-temperature reference aim curve by means of a manually operated variac. Electrical supply to the lens cooling air duct heaters and vacuum window heaters was a 28 V dc source chopped at a 400 cycle rate by the Harrell proportional temperature controller. Maximum output voltage from this controller to the duct heater is about 25.5 V. Total maximum power to the lens cooling air pre-heaters was about 100 watts (3.9 A).

12. Vacuum Source

Nelson Model #911 vacuum pump. Vacuum measured with 0 - 29.9" Hg calibrated vacuum dial gage.

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V. Experimental Set-Up and Test Apparatus (Cont'd.)

13. Cooling Air Supply

Six pounds per minute (3 pounds per minute to each vacuum window cooling cavity) metered through a Fisher-Porter Flowrator from the 80 psig building air supply facility. Air cooled to 75°F - 78°F, prior to use, by passage into a "can-interchanger" air-cooled on the outside by air ducted from the building air conditioning system.

[redacted]

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Enclosures (8)

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TABLE I

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TABULATION OF SEVERAL MEASURED AND COMPUTED TEMPERATURES*

LOCATION	TEMPERATURE °F FOLLOWING 2 HOURS HEATING							
	BLACK OVEN CAVITY $\epsilon \cong .8$				SHINY OVEN CAVITY $\epsilon \cong .1$			
	WITH HEATED WALLS		WITHOUT HEATED WALLS		WITH HEATED WALLS		WITHOUT HEATED WALLS	
	COMPUTED	MEASURED	COMPUTED	MEASURED	COMPUTED	MEASURED	COMPUTED	MEASURED
MIRROR AVERAGE	255	300	202	200	240	270	185	190
CENTER OF VACUUM WINDOW SURFACE INSIDE OVEN CAVITY	445	410	386	300	428	390	395	32[illegible]
EDGE OF VACUUM WINDOW SURFACE INSIDE LENS COOLING CAVITY	107	105	104	95	106	105	104	104
OVEN CAVITY AMBIENT	430	470	367	360	420	460	342	350
OVEN CAVITY WALL SURFACE	490	490	410	360	475	490	358	340

COMPUTED VACUUM WINDOW CENTER TO EDGE TEMPERATURE GRADIENT AT 400°F = -27°F
MEASURED VACUUM WINDOW CENTER TO EDGE TEMPERATURE GRADIENT AT 400°F = -2[illegible]

* NOTE: THE EXPERIMENTAL SET-UP USED IN THESE TESTS WAS NOT DESIGNED TO PROVIDE PERFECT HEAT TRANSFER SIMILARITY TO THE ACTUAL HARDWARE ON WHICH THE MATHEMATICAL MODEL FOR COMPUTATION WAS BASED.

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THERMAL PHOTOGRAPHIC TEST #13 - USING MIRROR - ISOTHERMAL LENS 7-11-62 DATA

HIGH EMISSIVITY (E≅.9) REFERENCE BLANKET ONLY POWERED; P = 1.5 PSIA; W = 3#/MIN CONTROLLED TEMP. COOLING AIR TO LENS VAC. WINDOW
LOW EMISSIVITY (E≅.1) OVEN CAVITY
LOW EMISSIVITY (E≅.1) MIRROR
W = 3#/MIN UNCONTROLLED " " " " OTHER VAC. WINDOW

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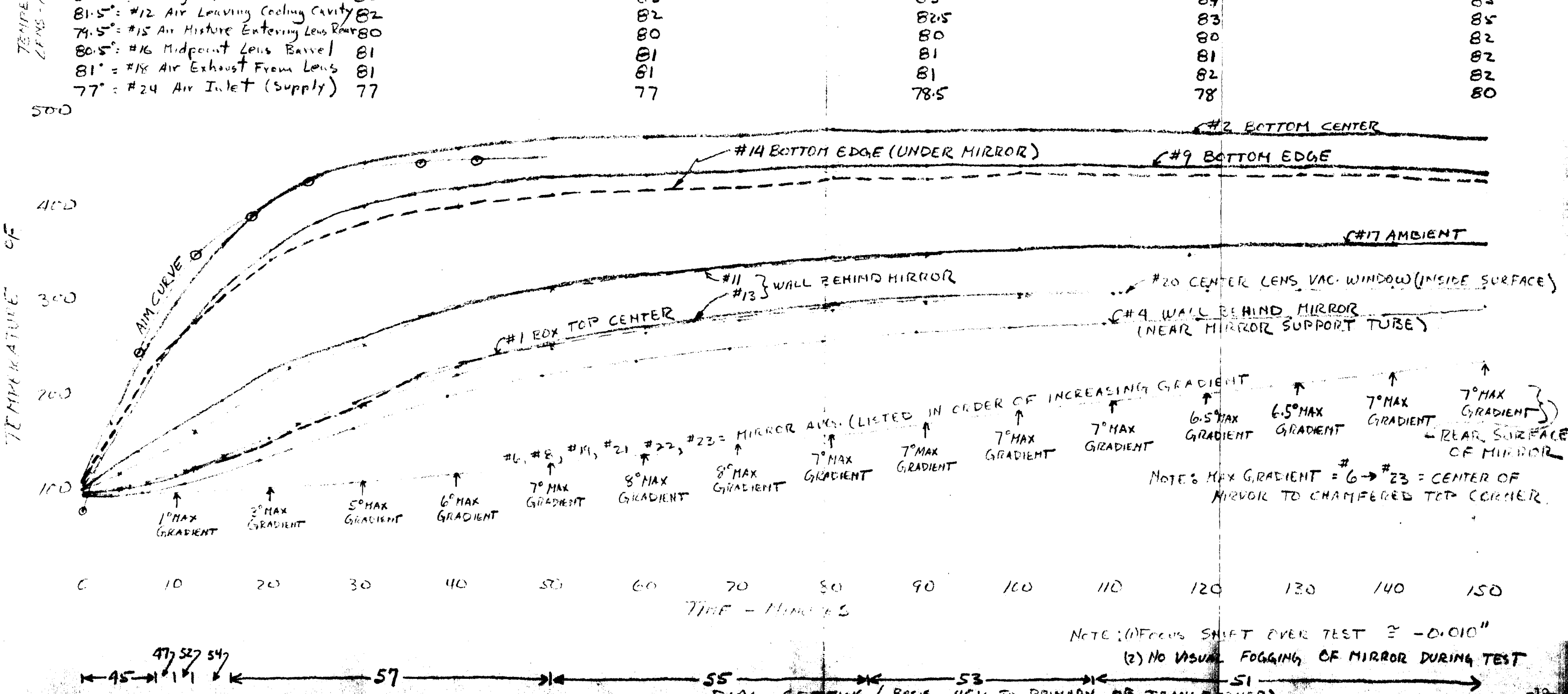
SO243 FILM RESOLUTION →
228/228 Microscope
128/128 1/1000 Strobe 0.6ND Filter
102/114 1/60 Sec Tungsten
143/128 1/1000 Strobe 0.6ND Filter
128/143 1/1000 Strobe 0.6ND Filter
114/114 1/60 Sec Tungsten Filament
1/60 Sec Tungsten Fil Exposures All To Light To Read. Reason Not Known But Suspect Camera Trouble
1/1000 Strobe Exposures Too Light. Camera Malfunction - Film Jam
1/1000 Strobe No Good Due To Rm Air Cond Oper.
128/114 1/1000 Strobe, 0.6ND Filter
114/128 1/1000 Strobe, 0.6ND Filter
72/114 1/60 Sec Tungsten
161/228 Microscope No SHIMMER

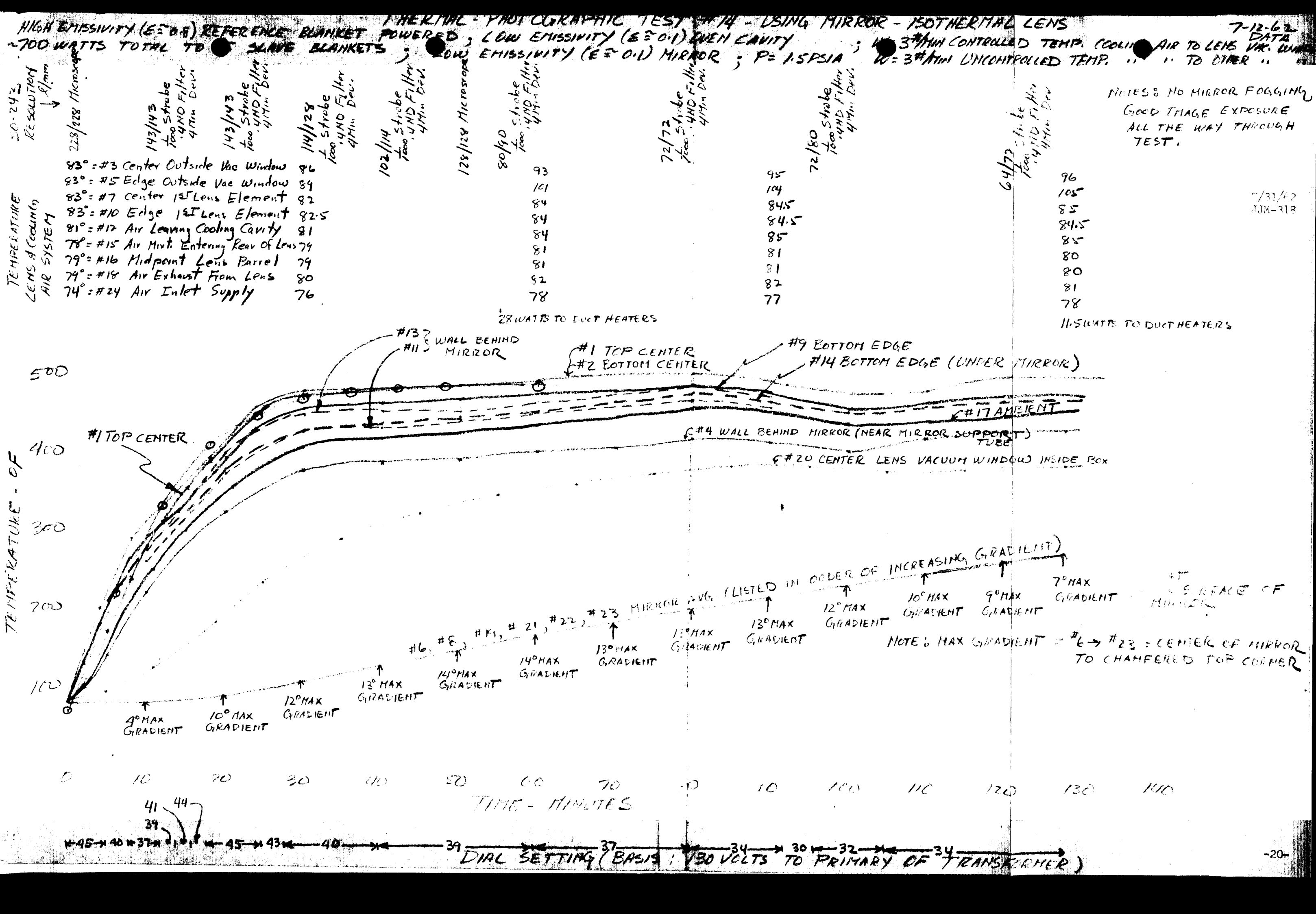
TEMPERATURE LENS - AIR SYSTEM

82° = #3 Center Outside Vac Window	84	87	89	90	93
81° = #5 Edge Outside Vac Window	85	93	101	103	104
81.5° = #7 Center 1st Lens Element	82.5	83	83	84	85
81.5° = #10 Edge 1st Lens Element	82	83	83	84	85
81.5° = #12 Air Leaving Cooling Cavity	82	82	82.5	83	85
79.5° = #15 Air Mixture Entering Lens Rear	80	80	80	80	82
80.5° = #16 Midpoint Lens Barrel	81	81	81	81	82
81° = #18 Air Exhaust From Lens	81	81	81	82	82
77° = #24 Air Inlet (Supply)	77	77	78.5	78	80



NOTE: (1) FOCUS SHIFT OVER TEST ≅ -0.010"
(2) NO VISUAL FOGGING OF MIRROR DURING TEST

← 45 → 47 52 54 ← 57 → ← 55 → ← 53 → ← 51 →
DIAL SETTING (BASIS: 115V TO PRIMARY OF TRANSFORMER)


THERMAL - PHOTOGRAPHIC TEST #14 - USING MIRROR - ISOTHERMAL LENS
7-12-62 DATA
HIGH EMISSIVITY (ε ≈ 0.8) REFERENCE BLANKET POWERED ; LOW EMISSIVITY (ε ≈ 0.1) OVEN CAVITY
~700 WATTS TOTAL TO 5 SLAVE BLANKETS ; LOW EMISSIVITY (ε ≈ 0.1) MIRROR ; P = 1.5 PSIA
W = 3#/MIN CONTROLLED TEMP. COOLING AIR TO LENS VAC. WINDOW
W = 3#/MIN UNCONTROLLED TEMP. " " TO OTHER "
20-243 RESOLUTION ℓ/mm
223/228 Microscope
143/143 1/1000 Strobe .4 ND Filter 4 Min Dev.
143/143 1/1000 Strobe .4 ND Filter 4 Min Dev.
114/128 1/1000 Strobe .4 ND Filter 4 Min Dev.
102/114 1/1000 Strobe .4 ND Filter 4 Min Dev.
128/128 Microscope
80/90 1/1000 Strobe .4 ND Filter 4 Min Dev.
72/72 1/1000 Strobe .4 ND Filter 4 Min Dev.
72/80 1/1000 Strobe .4 ND Filter 4 Min Dev.
64/72 1/1000 Strobe .4 ND Filter 4 Min Dev.
NOTES: NO MIRROR FOGGING, GOOD IMAGE EXPOSURE ALL THE WAY THROUGH TEST.
TEMPERATURE LENS & COOLING AIR SYSTEM
83° = #3 Center Outside Vac Window 86 93 95 96
83° = #5 Edge Outside Vac Window 89 101 104 105
83° = #7 Center 1st Lens Element 82 84 84.5 85
83° = #10 Edge 1st Lens Element 82.5 84 84.5 84.5
81° = #17 Air Leaving Cooling Cavity 81 84 85 85
78° = #15 Air Mixt. Entering Rear Of Lens 79 81 81 80
79° = #16 Midpoint Lens Barrel 79 81 81 80
79° = #18 Air Exhaust From Lens 80 82 82 81
74° = #24 Air Inlet Supply 76 78 77 78
28 WATTS TO DUCT HEATERS
11.5 WATTS TO DUCT HEATERS
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#13, #11 WALL BEHIND MIRROR
#1 TOP CENTER
#2 BOTTOM CENTER
#9 BOTTOM EDGE
#14 BOTTOM EDGE (UNDER MIRROR)
#17 AMBIENT
#1 TOP CENTER
#4 WALL BEHIND MIRROR (NEAR MIRROR SUPPORT TUBE)
#20 CENTER LENS VACUUM WINDOW INSIDE BOX
#6, #8, #K1, #21, #22, #23 MIRROR AVG. (LISTED IN ORDER OF INCREASING GRADIENT)
4° MAX GRADIENT
10° MAX GRADIENT
12° MAX GRADIENT
13° MAX GRADIENT
14° MAX GRADIENT
14° MAX GRADIENT
13° MAX GRADIENT
13° MAX GRADIENT
13° MAX GRADIENT
12° MAX GRADIENT
10° MAX GRADIENT
9° MAX GRADIENT
7° MAX GRADIENT
NOTE: MAX GRADIENT = #6 → #23 = CENTER OF MIRROR TO CHAMFERED TOP CORNER
TEMPERATURE - °F
500
400
300
200
100
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140
TIME - MINUTES
45 40 37 41 39 44 45 43 40 39 37 34 30 32 34
DIAL SETTING (BASIS ; 130 VOLTS TO PRIMARY OF TRANSFORMER)

HIGH EMISSIVITY (E ≅ 0.8) REFERENCE BLANKET ONLY POWERED ; P = 1.5PSIA ; W = 3#/MIN CONTROLLED TEMP. COOLING AIR TO LENS VAC. WINDOW UNIT 7-18-62 DATE
HIGH EMISSIVITY (E ≅ .8) OVEN CAVITY ; W = 3#/MIN UN-CONTROLLED " " " " OTHER VAC. WINDOW
LOW EMISSIVITY (E ≅ .1) MIRROR

THERMAL PHOTOGRAPHIC TEST #15 - USING MIRROR - ISOTHERMAL LENS

SO-243 FILM RESOLUTION →

90/102 - 1/1000 Strobe .6 ND Filter -.002" Focus Shift

114/114 - 1/1000 Strobe .6ND Filter -.004" Focus Shift

143/114 - 1/1000 Strobe .6ND Filter -.008" Focus Shift

203/228 Microscope Vibration Evident

128/114 - 1/1000 Strobe .6ND Filter -.005" Focus Shift

128/128 - 1/1000 Strobe .6ND Filter -.004" Focus Shift

90/102 - 1/1000 Strobe .6ND Filter -.010" Focus Shift

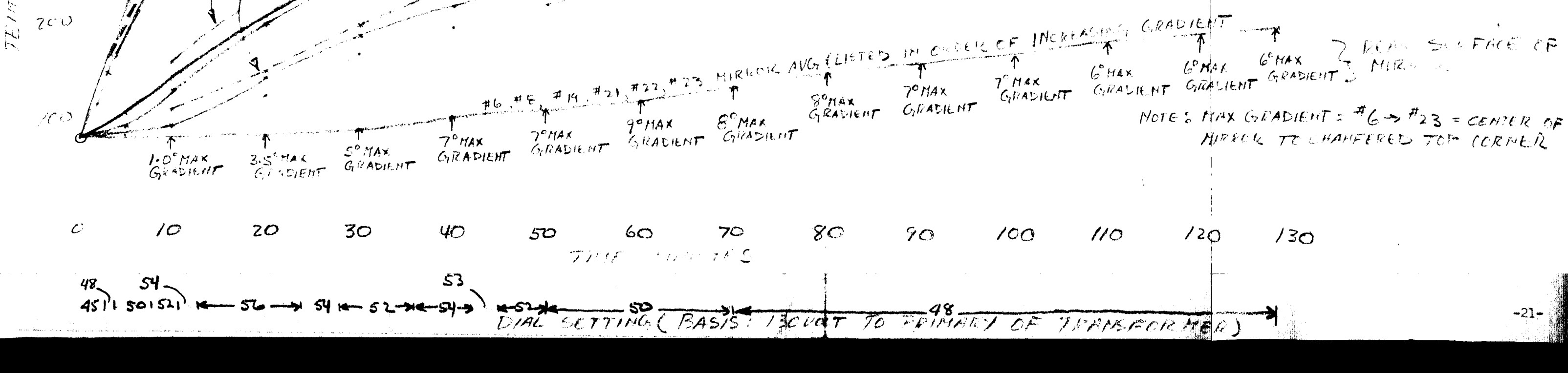
203/228 Microscope Lots of Vibration From People Moving On 1st Floor @ 5:00 PM

NOTE: NO VISUAL EVIDENCE OF MIRROR FOG DURING ENTIRE TEST

TEMPERATURE LENS COOLING AIR SYSTEM

79	#3 Center of Outside of Vac. Wind.	85	88	91	89
78	#5 Edge of Outside of Vac. Wind.	85	89	95	93
79	#7 Center 1st Lens Element	85	84	87	85
80	#10 Edge of 1st Lens Element	83	82	83	83
82	#12 Air Leaving Cooling Cavity	82	81.5	87	82
79	#15 Air Mixt Entering Rear of Lens	79	79	79	80
81	#16 Midpoint Lens Barrel	81	80.5	81.5	81
81	#18 Air Exhaust From Lens	81	81	81	82
75	#24 Air Supply To Lens	76	75	76.5	77

NOTE: DISCOVERED LARGE LEAK IN AIR SUPPLY TO COOLING CAVITY REPAIRED AT 90 MIN. MARK ALSO THERM. #7 WAS LOOSE AS DISCOVERED DURING NEXT TEST (#16) ON 7-19-62



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THERMAL - PHOTOGRAPHIC TEST #16 - USING MIRROR - ISOTHERMAL LENS 7-19-62

HIGH EMISSIVITY (E=.8) REFERENCE SOURCE ; LOW EMISSIVITY (E=.1) MIRROR ; P= 1.5 PSIA ; W= 3#/MIN CONTROLLED TEMP AIR TO LENS VAC WINDOW CAVITY DATA
HIGH EMISSIVITY (E=.8) OV[illegible] CAVITY W= 3#/MIN UNCONTROLLED TEMP AIR TO OTHER VAC WINDOW
~700 WATTS POWER TO FIVE SLAVE BLANKETS ON CAVITY WALLS

Film Focal.: 102/114 ± Strobe 1000 +0.008" — 143/114 ± 1000 Strobe +0.002" — 128/128 ± 1000 Strobe -0.002" — 143/181 Microscope — 128/102 ± 1000 Strobe -.006" — 114/72 ? ± 1000 Strobe -0.014" — 72/128 Microscope — Pictures No Good Since Focus Had Shifted Beyond Range Used — MIRROR FOGGED — Pictures No Good Since Focus Had Shifted Beyond Range Used In Test — 72/128 Microscope Smeary Image

TEMPERATURE OF LENS-COOLING AIR SYSTEM

#3 = Center Of Outside Of Vac. Wind.	80	90	104	95	95
#5 = Edge Of Outside Of Vac. Wind.	80	88	101	109	105
#7 = Center 1st Lens Element	80	84	93	85	85
#10 = Edge 1st Lens Element	81	82	86	85	85
#12 = Air Leaving Cooling Cavity	81	82	84	85	85
#15 = Air Mixt. Entering Rear Of Lens	80	81	81	81	82
#16 = Midpoint Lens Barrel	80	81	81	82	82
#18 = Air Exhaust From Lens	81	82	82	81	82
#24 = Air Supply To Lens	77	79	77	78	79

#7 THERMOCOUPLE WAS DISCOVERED TO BE LOOSE WAS CORRECTED AT 68 MIN

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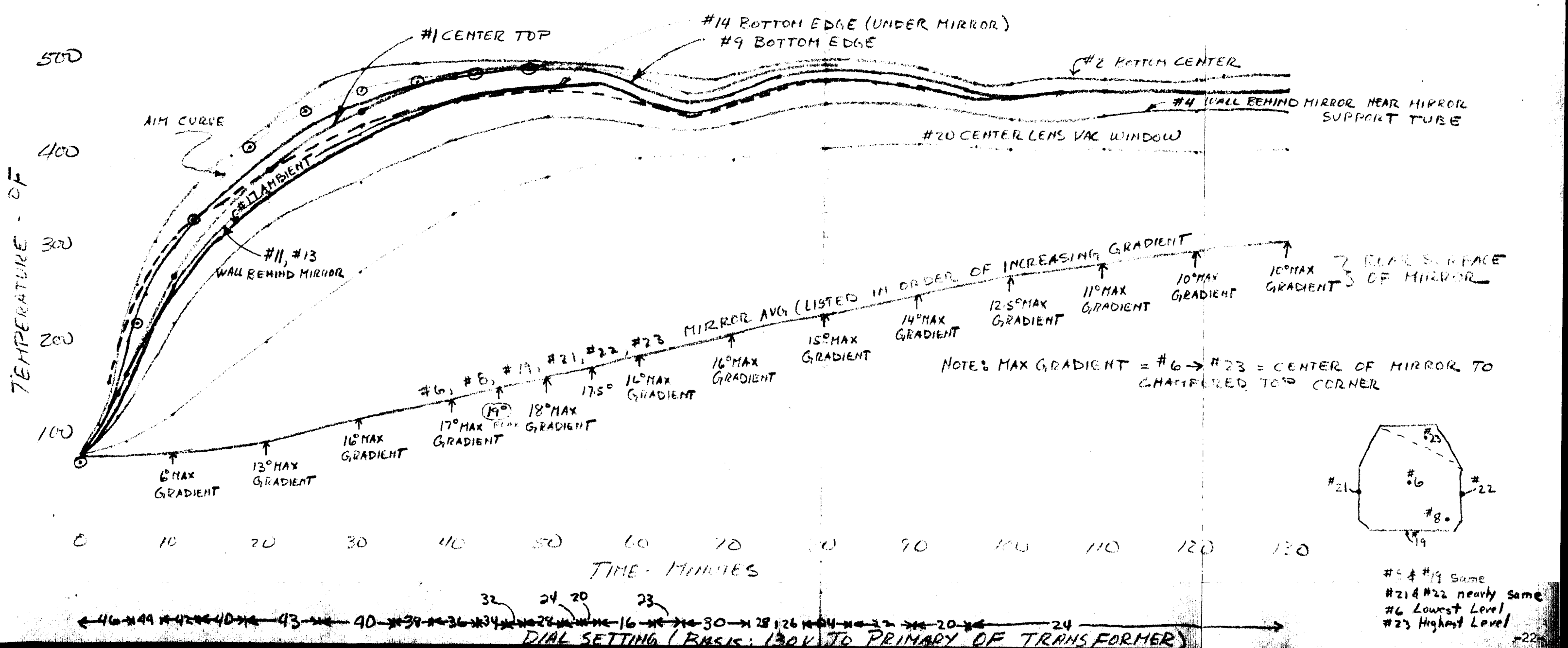

#8 & #19 Same
#21 & #22 nearly Same
#6 Lowest Level
#23 Highest Level

LOW EMISSIVITY (ϵ = .1) OVEN CAVITY; HIGH EMISSIVITY (ϵ = .8) REFERENCE BLANKET ONLY POWERED; THERMAL TEST #17 – MIRROR IN SYSTEM – ISOTHERMAL LENS; P = 1.5 PSIA; HEAT INPUT TO UNDERSIDE OF LENS COOLING JACKET

W = 2#/MIN CONTROLLED TEMP. COOLING AIR TO FIRST VAC. WIND. UNIT (THROUGH 20 ¼ ... HOLES)

W = 3#/MIN UNCONTROLLED TEMP. COOLING AIR TO OTHER VAC. WINDOW UNIT

7-25-62 DATA

LENS TEMP. °F

80°	#7 = Center 1st Lens Element	81°	83°	85°	55°
80°	#10 = Edge 1st Lens Element	81°	82.5°	80°	54°
80°	#16 = Exhaust Air	81°	81°	81°	81°
75°	= Environment Underside Of Lens Cooling Jacket	150°	143°	143°	143°

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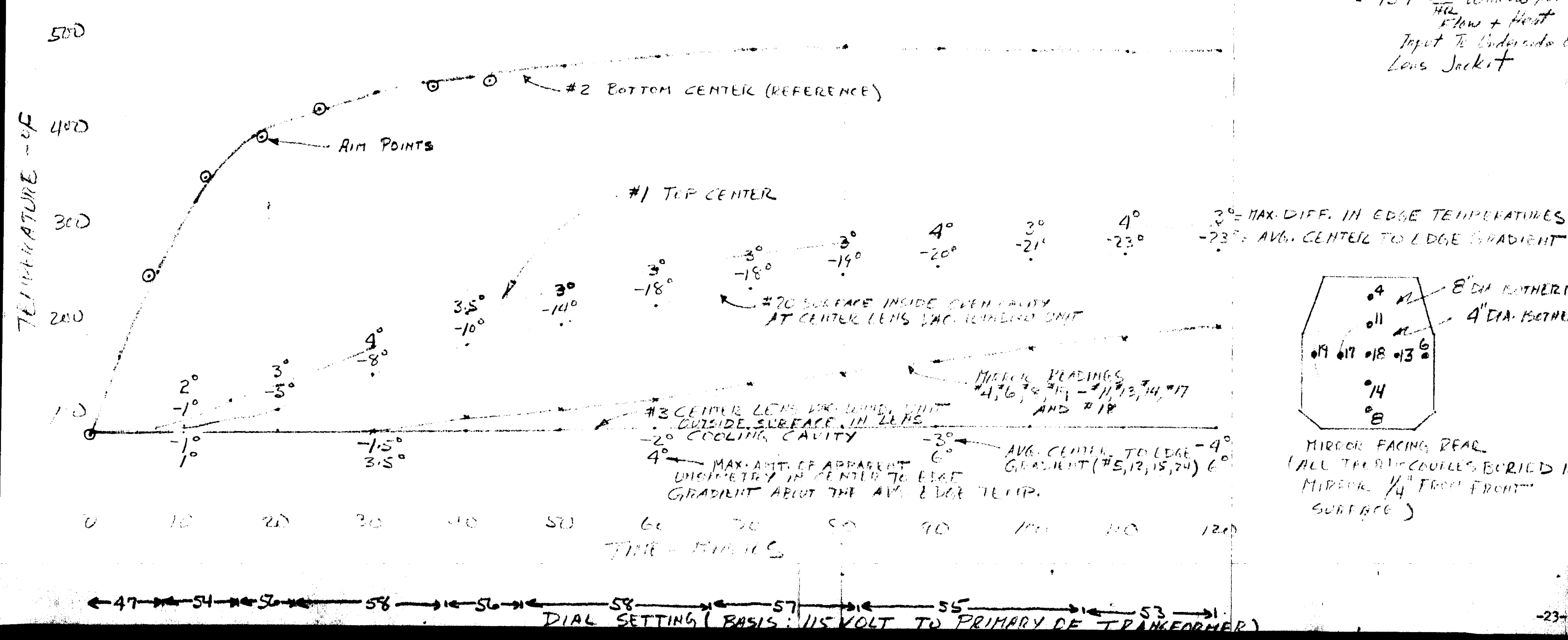
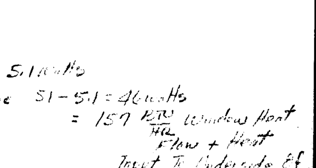
Watts → 51 46 38 33 23 18 12.8 8.9 6.4 5.1 ⟶ WATTS INPUT TO AIR PREHEATERS ⟶ 5.1 watts

Window 51 – 5.1 = 46 watts

= 157 BTU/HR Window Heat Flow + Heat Input To Underside Of Lens Jacket





MIRROR FACING REAR (ALL THERMOCOUPLES BURIED IN MIRROR ¼" FROM FRONT SURFACE)

THERMAL TEST #18 - MIRROR IN SYSTEM - ISOTHERMAL LENS

7-26-62 DATA

LOW EMISSIVITY (E = 0.1) OVEN CAVITY - HIGH EMISSIVITY (E = .8) REFERENCE ; P = 1.5 PSIA ; HEAT INPUT TO UNDERSIDE OF LENS COOLING JACKET
≈700 WATTS POWER TO CAVITY WALL HEATING BLANKETS
W = 3#/MIN CONTROLLED TEMP. AIR TO LENS VAC. WINDOW UNIT (THROUGH 70 - 3/16" HOLES) ; W = 3#/MIN UNCONTROLLED TEMP AIR TO OTHER VAC. WINDOW

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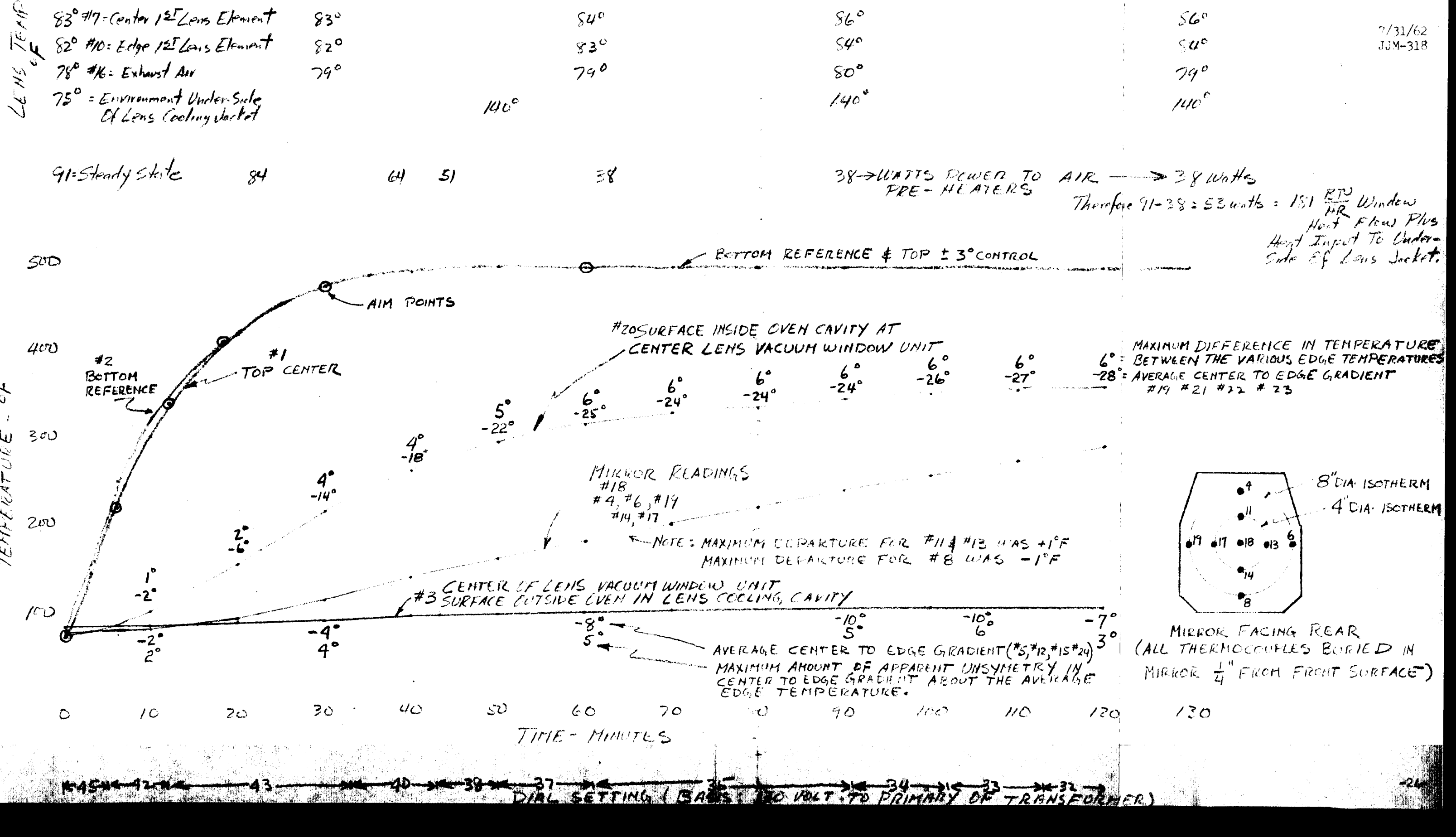

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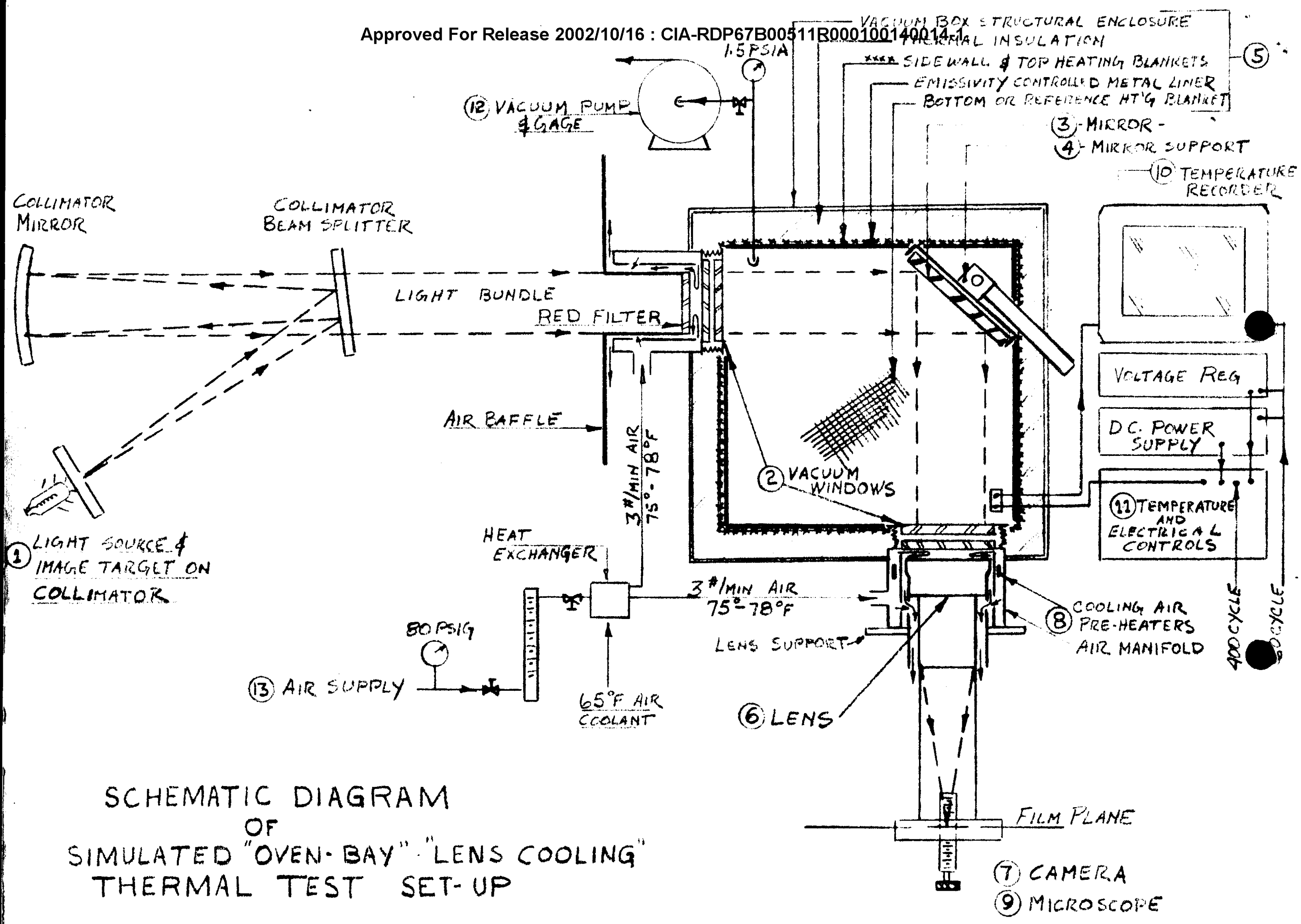

SCHEMATIC DIAGRAM
OF
SIMULATED "OVEN-BAY" "LENS COOLING"
THERMAL TEST SET-UP

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